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DEVELOPMENT SCHEDULE FOR THE ROLLING RESISTANCE TRAILER

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by

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ABSTRACT

This paper describes the development schedule for the rolling resistance trailer and details the addition of new sensors and modifications to old sensors. As well as describing the future develoment of the trailer hardware this report also considers the question of future software development for the data acquisition system.

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CALENDRIER DE MISE AU POINT DE LA REMORQUE DESTINÉE A LA MESURE DE LA RÉSISTANCE DE ROULEMENT

par

R.J. Kolada*

RÉSUMÉ

Le présent rapport décrit le calendrier de mise au point de la remorque destinée à la mesure de la résistance de roulement et traite en détail de l'addition de nouveaux capteurs ainsi que des modifications des anciens capteurs. En plus de décrire les perfectionnements prévus du matériel de la remorque, le rapport traite de l'élaboration future de logiciel destiné au système d'acquisition de données.

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1.0 INTRODUCTION

This report presents a timetable for the future development of the rolling resistance trailer and describes the modifications and test procedures that will be implemented.

The objectives of developing a vehicle capable of measuring the rolling resistance experienced by mine haulage trucks are as follows;

1.1 IMMEDIATE OBJECTIVE

To prove that the trailer and data processing is capable of measuring the rolling resistance of a road as experienced by the trailer. Once the trailer has been proven to be capable of achieving this objective then the measurements of rolling resistance obtained by the trailer will be correlated to the rolling resistance experienced by mine haulage trucks using direct pull tests.

The correlation between the rolling resistance measured by the trailer and that experienced by mine haulage trucks is necessary since they are likely to be different due to differences in geometry, axial loading, gross vehicle weight, etc.

1.2 INTERMEDIATE OBJECTIVES

Measure the rolling resistance of entire mine haul routes over a period of a year in order to evaluate seasonal variations, (i.e. rain, frost). This will include measurement of road material conditions, i.e. strength, moisture, density, etc.

1.3 LONG TERM OBJECTIVES

Evaluate the economic effects of haulroad rolling resistance on the productivity of mine haulage fleets.

Evaluate road construction methods and materials which provide the best return for the investment.

The intermediate and long term plans have been described above simply to provide background information. This document is primarily concerned with the short term objectives and hov they will be achieved.

2.0 INSTALLATION OF NEW OR MODIFIED EQUIPMENT

The inclinometer and towbar load cell sensors have proven to be reliable and will remain unchanged. Initial trials with the trailer have shown that the trailer velocity sensor requires modification.

Three additional sensors will be added to the trailer, these are:

Triaxial accelerometer;

Truck velocity sensor;

Additional trailer velocity sensor.

The triaxial accelerometer will provide data on a number of parameters such as; the vertical vibrations of the trailer due to road roughness; yaw of the trailer, again due to road roughness and due to cornering; and the change in acceleration of the trailer in the direction of travel.

Most highway vehicles are equipped with a sensor which is used for cruise control. However, this sensor is not hooked up unless the cruise control option is fitted, as with the trailer towing truck. Connecting this sensor to the data acquisition system simply requires connecting the wires from the sensor (which lie unconnected behind the dashboard) to the computer interface. The sensor is a 'hall effect switch' which switches between zero and five volts when a magnet passes the sensor. The transition between the two voltage states is extremely rapid and is therefore relatively immune to electrical noise which often plague other types of sensors.

The additional velocity sensor on the trailer is a simple bicycle generator and hence will provide a direct voltage analogue output in response to the rotational velocity of the trailer wheel. The reason for using two velocity sensors on the trailer is to evaluate which sensor is preferable and also to provide backup capability should one fail.

3.0 SOFTWARE DEVELOPMENT

3.1 DATA ACQUISITION SOFTWARE

The current data acquisition software should be re-written in Modula 2. It is a small program whose only complexity is the 64k

segmentation of the PC memory. Modula 2 will handle this problem automatically requiring no additional programing.

A rewrite of the program should include an increase in sophistication. The possibility of writing the program to include event markers and to handle variable numbers of sensors should be examined. The style and documentation of the program will be at a premium.

The new program will incorporate a decision, ye to be made, on velocity sensors installed on the trailer wheels. The choices are:

1) Continue with a digital wheel pulse sensor technique with modifications to eliminate present problems.
2) Return to a fixed sample rate with respect to time producing an analogue output from a direct voltage generator sensor.
3) Utilize both types of sensors or at least have the software capable of switching between the two.

3.2 DATA PROCESSING

The processing of data in the field can be time consuming on the PC clone used to gather the data. This is due to the extent of the number crunching that is necessary to process the data. Consequently, a Toshiba AT clone will be used to complete the data processing and provide reports to the mine site at the time of testing.

3.3 SOFTWARE DEVELOPMENT

An additional AT&T computer will be set up with an identical data acquisition card as used in the trailer. Thus software can be tested with sensors in the office with reasonable confidence that they will work in the field.

4.0 TRIAL TEST RUNS

In order to prove that the trailer is capable of obtaining repeatable results of rolling resistance over the same section of road a series of test runs over roads of varying rolling resistance will be necessary.

To achieve this the force experienced by the load cell in the towbar will have to be corrected to offset forces that occur due to the

vehicle accelerating or decelerating, or ascending or descending a grade. These factors will produce forces in the towbar that are not attributable to the rolling resistance of the road but are instead due to linear and rotation inertia and to frictional and gravitation forces. The corrections that are made to offset these forces are produced in Appendix A.

The proof that the corrections made to the force experienced by the lead cell are correct will be a reproducible value of rolling resistance for a given test section of road that is not affected by taking the measurements with the trailer while it is speeding up or slowing down. These tests should also be conducted on roads that have a significant grade to show that the same values of rolling resistance are obtained whether the measurements are taken uphill or downhill while again varying the acceleration of the trailer.

5.0 TESTING SCHEDULE

TASK	Date of Initiation	Date of Completion
Installation of conduit, wiring and control panels in the towing truck.	1 November	7 November
Installation of triaxial accelerometer	8 November	10 November
Connection of all sensors to the data acquisition system.	14 November	30 November
Trial runs to test full operation of both hardware and software and debug any problems.	1 December	17 December
Test runs to measure rolling resistance of selected test sections of road.	3 January	10 January
Processing of test run data and correlation of results.	10 January	28 January
Development of a standard pre run calibration checking procedure.	1 February	7 February

APPENDIX A

6.0 CALCULATION OF ROLLING RESISTANCE

The force supplied by the towing vehicle to the trailer, as measured by the load cell, is dissipated in overcoming the following, primary, retarding forces:

1) Rolling resistance of the haulroad.
2) Rolling resistance of the tires.
3) Gravitational attraction when travelling uphill; i.e. the force required to pull the trailer uphill against gravity. This quantity is negative when travelling downhill.
4) Linear inertia of the trailer to acceleration. This force is negative when decelerating.
5) Rotational inertia of the wheels and any other rotational masses when accelerating. This force is negative when decelerating.
6) Frictional resistance of the trailer wheel bearings and any other frictional forces applied to the rotating masses.

The term rolling resistance is generally considered to be the relationship between the rimpull force required to move the vehicle and the gross vehicle weight. This relationship assumes the vehicle to be moving at a constant velocity on a level road. The bulk of the resistance which has to be overcome by the rimpull force is caused by two effects: compression of the road material and the flexure of the tire, i.e. 1 and 2 listed above. It is the force due to these effects (1 and 2) which we wish to measure and therefore we must deduct the forces resulting from effects 3 to 6 from the total force imparted to the drawbar.

The linear inertia of the trailer is easily corrected for, if the weight of the trailer and the trailer velocity are known. The rotational inertia of the wheels and friction of the rotating masses can be calculated by performing a simple experiment as described below.

6.1 CALCULATION REQUIRED TO CORRECT TOWBAR FORCE TO FIVE ROLLING RESISTANCE

The corrections required to the towbar force are given below. By applying these corrections to the measured towbar force the result should provide the force that is necessary to overcome rolling resistance only.

6.1.1 Gravitational Force

Force on the trailer due to gravity. This is the extra force on the towbar required to travel uphill or the force needed to retard the trailer when travelling downhill.

The correction is given by the equation:

$$-(mg \sin \tau)$$

Where m = mass of the trailer,
g = acceleration due to gravity,
τ = angle of the uphill grade (this is negative if downhill).

6.1.2 Linear Inertia

The correction for linear inertia is only required if the trailer is accelerating or decelerating. Experience has shown that it is difficult to maintain the trailer at a constant velocity during test runs and consequently this correction is necessary. The correction can be calculated from Newton's laws of motion i.e.:

$$f = ma$$

Where f = force required to accelerate a mass m, where a = acceleration. Since the mass of the trailer is known then only the amount of acceleration of the trailer need be calculated. This is given by Newton's second law of motion;

$$v^2 = u^2 + 2as$$

$$\text{or} \quad a = (v^2 - u^2) / 2s$$

Where u = initial velocity
v = velocity after a short time interval
s = distance travelled between readings of u and v.

Substituting back into the preceding equation

$$f = m(v^2 - u^2) / 2s$$

This force has to be deducted from the towbar force. By monitoring velocity within a short time interval it is possible to calculate trailer acceleration with sharp response to any changes.

6.1.3 Measurement of Frictional and Rotational Inertial of the Trailer Wheels

The method used to measure the rotational and frictional forces of the trailer requires one of the trailer wheels to be raised off the ground. A thin flexible wire is then wound several times around the circumference of the tire which is then passed through a pulley arrangement. A known weight is suspended from the wire at a measured height above the ground and then released. The potential energy of the falling weight is imparted to the wheel in the form of rotational kinetic energy and is also consumed in overcoming friction of the wheel. A small amount of the energy is also lost in the form of kinetic energy when the weight stikes the ground. The equation governing the transfer of energy is as follows:

$$Mgh = 1/2\ Mr^2w^2 + 1/2\ Iw^2 + nf, \quad \ldots\ldots\ldots \quad (1)$$

Where M = the mass of the weight,
h = the height from which the weight is dropped and
g = acceleration due to gravity.

The term $1/2\ Mr^2w^2$ is the kinetic energy of the weight upon striking the ground,

Where r = the outside radius of the tire and

w = the angular velocity (radians per second) of the wheel when the weight hits the floor.

The term $1/2\ Iw^2$ is the kinetic energy imparted to the wheel,

Where I = the moment of inertia of the wheel.

The term nf is the energy expended in overcoming frictional forces,

Where n = the number of rotations the wheel makes before the weight hits the floor, and
f = the energy per turn expended against friction.

The value of f can be calculated by counting the further number of turns the wheel makes after the weight hits the floor (n_1) and timing how long this takes before the wheel comes to rest (t). f is then given by the equation:

$$f = 1/(2n_1)\ Iw^2 \quad \ldots\ldots\ldots \qquad (2)$$

Substituting for f into equation 1:

$$Mgh = 1/2\ Mr^2w^2 + 1/2\ Iw^2\ (1 + n/n_1) \quad \ldots\ldots\ldots \qquad (3)$$

$$\text{or } I = (Mgh-(Mr^2w^2/r))\ /\ ((1/2)w^2(1 + n/n_1)) \quad \ldots\ldots\ldots \qquad (4)$$

Since the angular velocity of the wheel when the weight hits the ground is w, and the final angular velocity after time t is zero, then the average angular velocity is $w/2 = 2(pi)n_1/t$. Hence $w = 4(pi)n_1/t$. Knowing w, t, h, M and r, the moment of inertia I can be calculated from Equation 4. From nine readings using three different weights from approximately the same height, the moment of inertia of one wheel of the trailer was found to equal 17.7 plus or minus 1.5 kg m^2. This value of I can be used to calculate a correction to the force measured by the tow bar load cell to accunt for the rotational energy absorbed by the two wheels of the trailer when accelerating or released when decelerating. Also the friction of the

wheels to rotation can also be corrected for. The coeficient of friction $(1+n/n_1)$ for the trailer is approximately 1.07.

6.2 INCLINOMETER CORRECTION

Unlike the corrections above which deal with the towbar force to calculate rolling resistance, this correction is just to offset the error of the inclinometer. This error occurs due to changes in the acceleration of the trailer which swings the pendulum of the inclinometer. Hence the reading of the inclinometer does not give the true grade of the road which is required. To visualize the effect of changes in acceleration on the inclinometer imagine the trailer to be accelerating at a constant rate on a level road . The inclinometer will swing backwards due the acceleration giving a false reading of the grade of the road as depicted in Figure 1.

The amount that the pendulum will swing backwards will be proportional to the trailer acceleration compared to the acceleration due to gravity. For example, if the trailer accelerated at a constant rate of $10m/s^2$ which is the same as the acceleration as due to gravity, then the pendulum will swing backward at an angle of 45 degrees. From Figure 1 the angle of the pendulum due to acceleration of the trailer is given by:

$$\text{Tan } \sigma = a/g$$

Where a = acceleration of the trailer
g = acceleration due to gravity

The correction to the inclinometer is then given by;

$$o = \text{Tan}^{-1} (a/g)$$

This corection should obviously be applied to the inclinometer readings before attempting to calculate the gravitational force correction to the towbar as described in Section 6.1.1. The acceleration a, can be calculated as described in Section 6.1.2.